Dynamic Stand Allocation CSOP using Genetic Algorithm

Description. Approach. DEMO

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About AirportLabs

R&D company, developing innovative products to make aviation more efficient

Founded in Jan 2015

Fully Product Oriented - extensive software and hardware capabilities

Dedicated Customer Success Team

Currently 7 released products for aviation, more in the pipeline

40 Engineering Staff

- Over 12 years experience in designing, building and operating airport systems
- 15 years experience in software development
- 10 years experience in electronic control systems
- Collaboration with technical universities for research

Stand Allocation (Planning) Problem

General Problem Description

- Stand - designed area intended to be used for parking an aircraft
- Aircraft turn-round - set of processes from the time an aircraft arrives at its arrival stand until it departs from its departure stand (IBT - OBT)
- *Allocate stands to aircrafts during turn-round processes aiming to:*
  - *avoid conflicts (CSP)*
  - *maximize the evaluation function (KPIs)*
- Resource allocation in planning
- Constraint Satisfaction Optimization Problems (CSOP)
- **CSOP** = (Turn-rounds, Stand domain, SA Constraints, SA f-function)
- Search space: $|stands|^{|turns|}$ - intractable with complete methods (NP)

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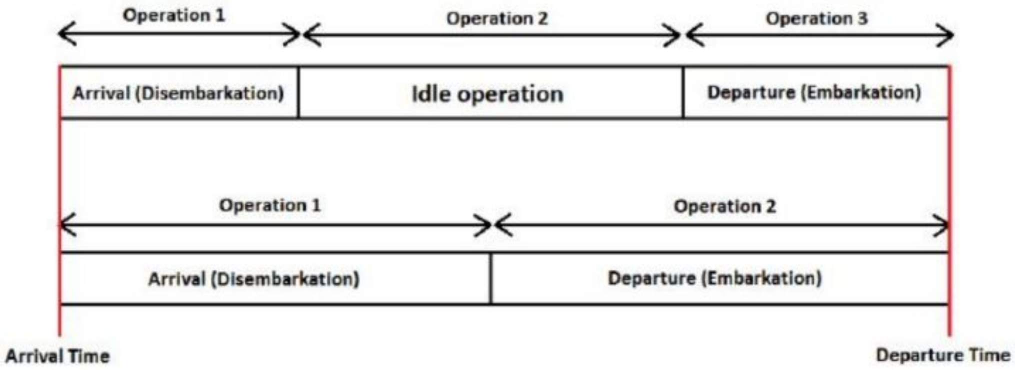
Stand Allocation Variables

Aircraft Turn-rounds

- Identify the turn-rounds based on the triplet (arrival, departure, aircraft)
  - Aircraft: information about the physical aircraft
  - Arrival flight: information about the arrival nature
  - Departure flight: information about the departure nature
- Turns can be split in 3 parts by *towing*



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Stand Allocation Constraints (1)

Node/Unary/Pairing Constraints

- The constraints are creating a compatibility profile for every turn/part.
- The **domain** of each turn is composed by a set of stands.
- Unary -> could be individually verified one single time
- Node consistency

Constraint Components

1. Turn attributes (e.g. aircraft physical sizes, service type, origin, destination, terminal etc.)
2. Stand attributes (e.g. max length, max width, gate, MARS, contact/remote, terminal etc.)

E.g. 01M AIRCRAFT WINGSPAN <= 3805 AND AIRCRAFT LENGTH <= 4732

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Stand Allocation Constraints (2)

Arc/Relative (to other turns)

- Verified in the context of more than one turn-round and/or more than one stand
    a. Stand Adjacency constraints
        i. Size Constraints (e.g. one large code D/E/F on M or two medium (small) code C/B/A on L and R, etc.)
        ii. Time Constraints (e.g. 45 min departure separation on MARS, Pushback, etc.)
    b. Capacity (i.e. stand must be available) / Buffer time constraints
    c. Constraints for preventing cross-flow
    d. Gate capacity constraints (i.e. gate allocation)
    e. Safety constraints

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Stand Allocation Constraints (3)

Constraint Types

1. Hard (Mandatory) constraint (e.g. physical, capacity):
    a. must be true with no exceptions
    b. determinantes the validity of the solution

2. Soft (Score) constraint:
    a. true if possible
    b. prioritise according to its score

Stand Allocation KPIs (1)

Soft Rules Score

- Airline preferences and good allocation practices
- Objective: maximize the soft rules score

Pier Service Level

- Two types of stands
  - Contact stands (the stand is connected to a gate)
  - Remote stands (the passengers need to be coached from/to the gate)
- Pier Service is a calculation (by terminal) of the percentage of passengers served at *contact* stands
- Usually the most important performance metric
- Objective: max *Pier Service Level*

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Stand Allocation KPIs (2)

Tows

- Def: The process of moving an aircraft from one stand to another
- The basis for doing towing is to increase the PSL
- Tow Off: moving from contact to intermediate remote
- Tow On: moving from intermediate remote to contact
- The tows, like the stands, are allocated automatically
- Objective: minimize no. of tows

Stand Use Efficiency

- Robustness score - having large enough and fairly distributed buffer times in order to avoid possible overlays on the same stand or adjacency conflicts
  - *Predictions* for buffer time
- Fitting score - minimise the proportion between stand measures and aircraft physical measures

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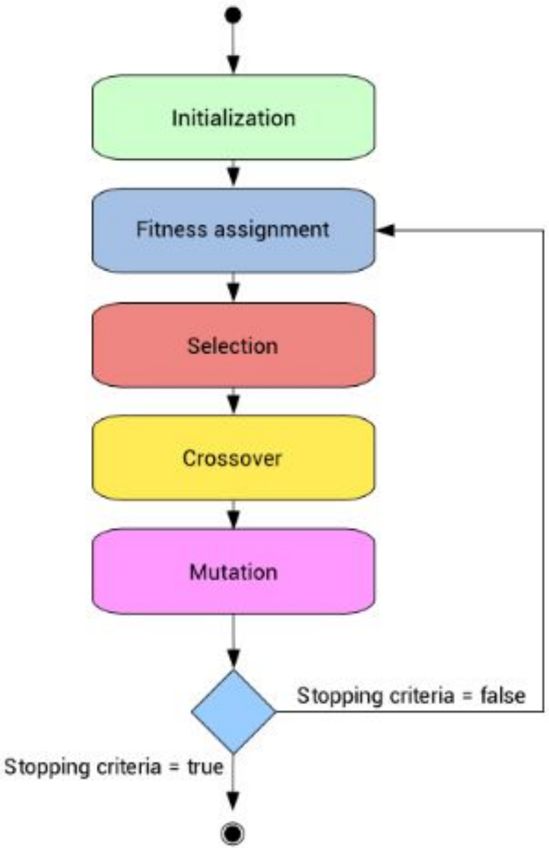
Genetic Algorithms

Definition

- Metaheuristics stochastic search methods based on populations (not a single point) of potential solutions and mechanics of natural genetics
- Steps:
  - Initialization: create the initial population of genomes
  - Fitness assignment: calculate the fitness of every genome (how good the solutions are)
  - Selection: select genomes for crossover (highest fitness value -> higher probability)
  - Crossover: swap partial genomes of the fittest of the older genomes
  - Mutation: sometimes introduce new genes



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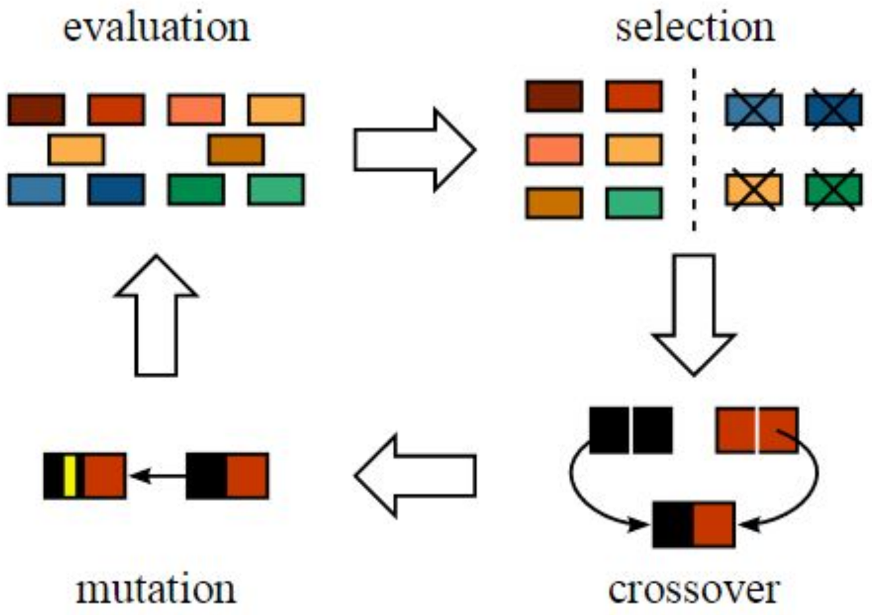
Genetic Algorithms

Genetic Process



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Stand Allocation Genetic Algorithm

Genome / Chromosome

$towDecision(turn_i),\ i \in [1,\ N],\ \ where\ \ N = no.\ of\ turns$

$$towDecision(turn_i) = \begin{cases} 1, \text{ if the turn is towed (split in 3 parts)} \\ 0, \text{ if the turn is not towed (1 part)} \end{cases}$$

$allocatedStand(part_i),\ i \in [1,\ M],\ \ where\ \ M = no.\ of\ parts$

$no.\ of\ parts = no.\ of\ turns + 3 \cdot no.\ of\ towable\ turns$

$allocatedStand(part_i) \in Domain(part_i) \cup \{null\} \subseteq Stands \cup \{null\}$

$$boxType(part_i) = \begin{cases} B, \text{ } part_i \text{ is equivalent to a complete turn} \\ A, \text{ } part_i \text{ is an arrival part} \\ T, \text{ } part_i \text{ is an idle(tow) part} \\ D, \text{ } part_i \text{ is a departure part} \end{cases}$$

$allocatedStand(part_i) = null\ \ iif:$
$towDecision(turn(part_i)) = 0\ \ \&\&\ \ boxType(part_i) \neq B$
OR
$towDecision(turn(part_i)) = 1\ \ \&\&\ \ boxType(part_i) = B$

Towing decision

Turn1	Turn2	Turn3	...	TurnN
true	false	false	...	false

Allocated Stand

Part1	Part2	Part3	...	PartM
NULL	36	04	...	12

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Stand Allocation Genetic Algorithm

Genome / Chromosome

- The chromosome does encapsulate information about:
  - Towing decisions for each turn: true/false
  - Parking positions for each part: allocated stand
  - Playground: data structures that facilitate and accelerate the creation and reparation of genomes and the verification of the arc constraints:
    - Timeline matrix
      - View of adjacency constraints
      - Fast stand and time area identification using start slot, end slot
    - Occupancy intervals
      - Fast identification of occupied areas

$$timelineSlots(part_i) = \left(\frac{ArrivalTime - AllocationStartTime}{granularity} \quad \frac{DepartureTime - AllocationStartTime}{granularity} \right)$$

	1	2	3	4	5
01M	P1	P1	P1	P1	P1
02M		P2	P2	P3	
03M		P5	P5		P6
04M				P3	P3
...					

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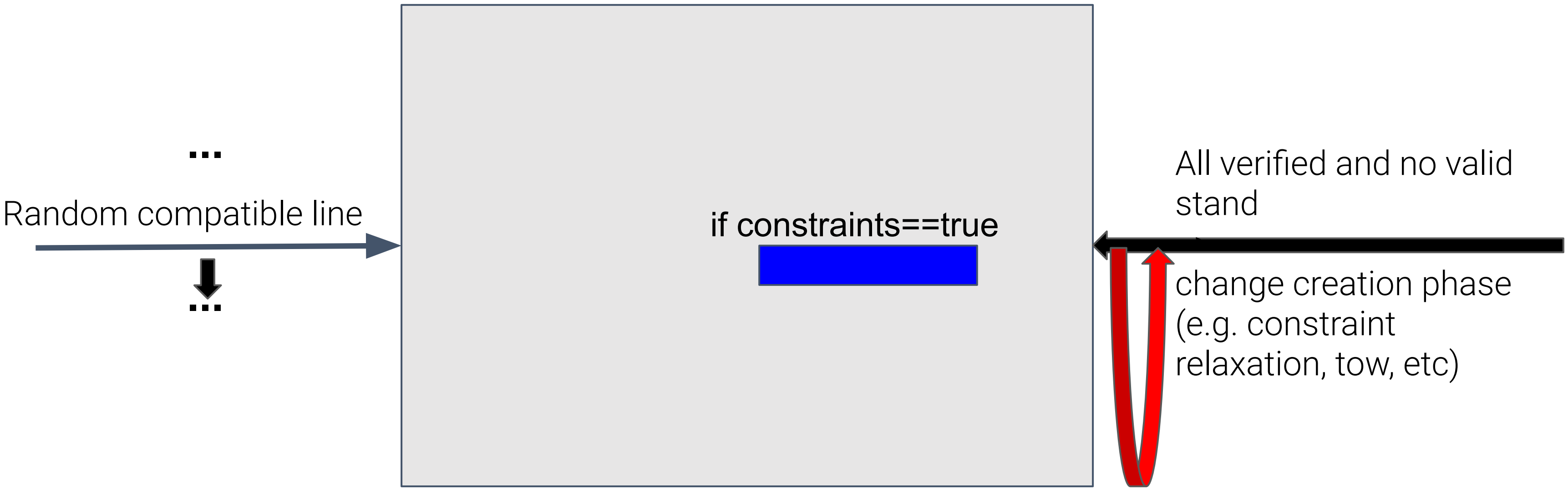
Stand Allocation Genetic Algorithm

Initialization / Population creation

For all turns (greedy sorting based on ground time, no. of compatible stands, etc.):



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Stand Allocation Genetic Algorithm

Selection

- Tournament using 70% of genomes (population:100)

Crossover

- Combining bits of 2 parents (e.g. one-split, n-split)
- Repair (adjust) the chromosome using the matrix playground:
    - Inherited part value represents the first stand option
    - Instead of a random stand (as in the creation methods), we use the stand inherited from one of the parents
    - The resulted stand is final

Mutation

- Changing random tow decision or allocated stand values

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Stand Allocation Genetic Algorithm

Evaluation / Fitness function

- Invalid if there are any violations (=0)
- Weighted sum
  - PSL
  - No. of tows
  - Soft Rules score
  - Stand Use Efficiency
  - Others (e.g. …)
- Function constraints
  - Overall, per day (e.g. 24h time frame: actual day & next day)
  - PSL > x (e.g. PSL > 95%)
  - No. of tows < y (e.g. No. of tows < 75)

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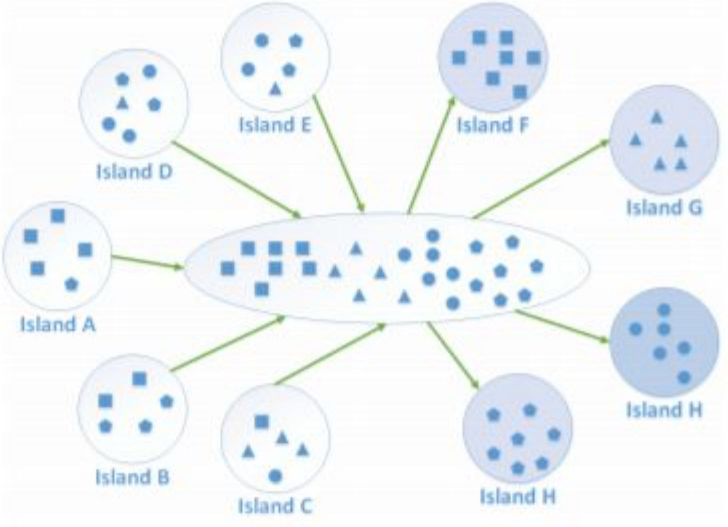
Stand Allocation Genetic Algorithm

Multi-population (Island)

- Advantages:
  - Converge faster
  - Facilitate multi-objective optimization: island that are using different fitness weights



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Stand Allocation Genetic Algorithm

Approach

- Advantages:
  - Adaptability
    - continuous solution optimization
    - dynamic reuse of old solutions after data update
  - Scalability: unlimited horizontal scalability
    - Multithreaded chromosome formation
    - Multisystem islands

Stand Allocation Logic

Event sequence

- Read Data: turn-round, parts, stands, rules, airport structure, genetic algorithm settings etc.
- Set turn-round allocation attributes: blocked on stand, blocked as tow, towable, etc.
- Get previous best solutions
- Initialize the genetic algorithm
- Repeat until stop condition
  - Create new solutions (initialization or crossover)
  - Evaluate the new solutions (multi-threaded)
  - Select for crossover + add mutations
- Update the turn-rounds in accordance with the best solution (parking positions, tows, etc.)
- Save the best solutions

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Results

LGW Instance

- Constraints: Solution adhered to all the mandatory constraints
- Robustness: ~97% of the aircrafts are assigned without being needed other interventions in the 70m freeze time window (3% of aircrafts are affected by late changes)
- PSL constraint > 95%
- No. of tows constraint < 75

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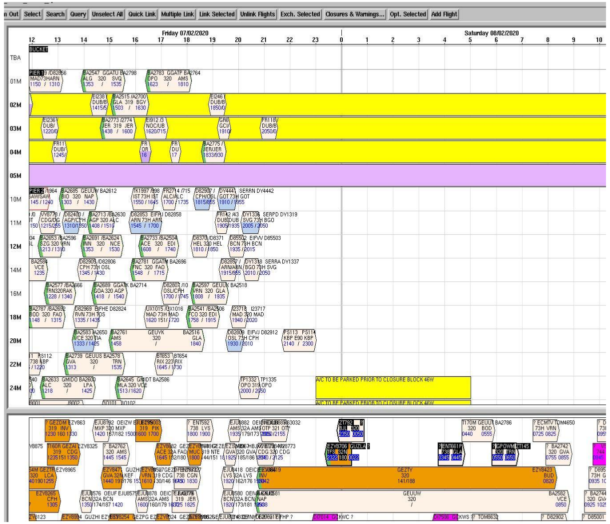
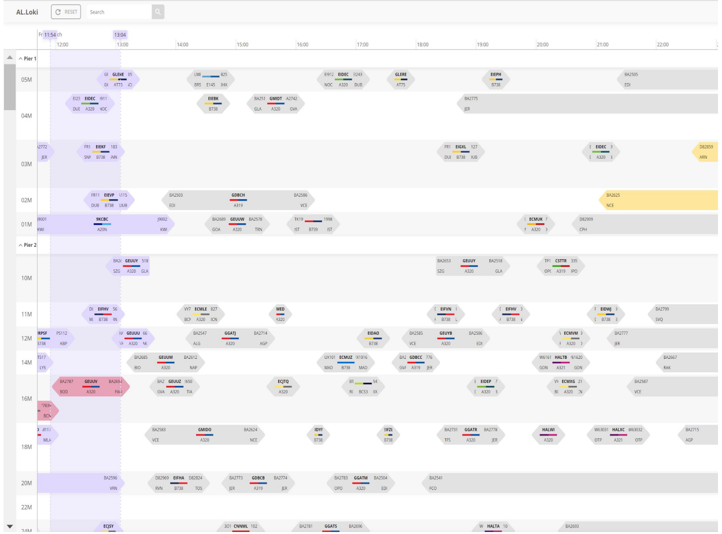
Demo


Select
Search
Query
Unselect All
Quick Link
Multiple Link
Link Selected
Unlink Flights
Exch. Selected
Closures & Warnings...
Opt. Selected
Add Flight
Friday 07/02/2020
Saturday 08/02/2020


AL.Loki
RESET
Search
Pier 1
Pier 2

Thank you.

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